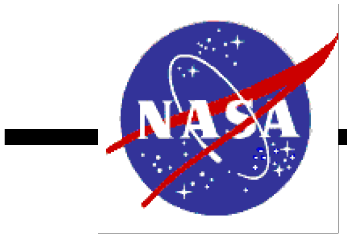
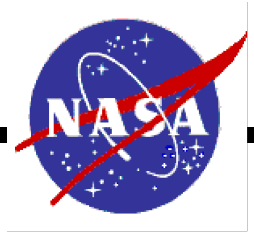




# Mission Integration

Larry Fineberg
NASA Systems & Integration Engineer
Kennedy Space Center, FL



# Agenda



- Where I Work
- Who am I?
- Build Me A Spacecraft
- Go Get Me A Rocket
- Lessons Learned
- Questions & Answers

# Where I Work
# NASA's Launch Services Program



- Open file titled "LSP-Overview-020514-Fineberg"

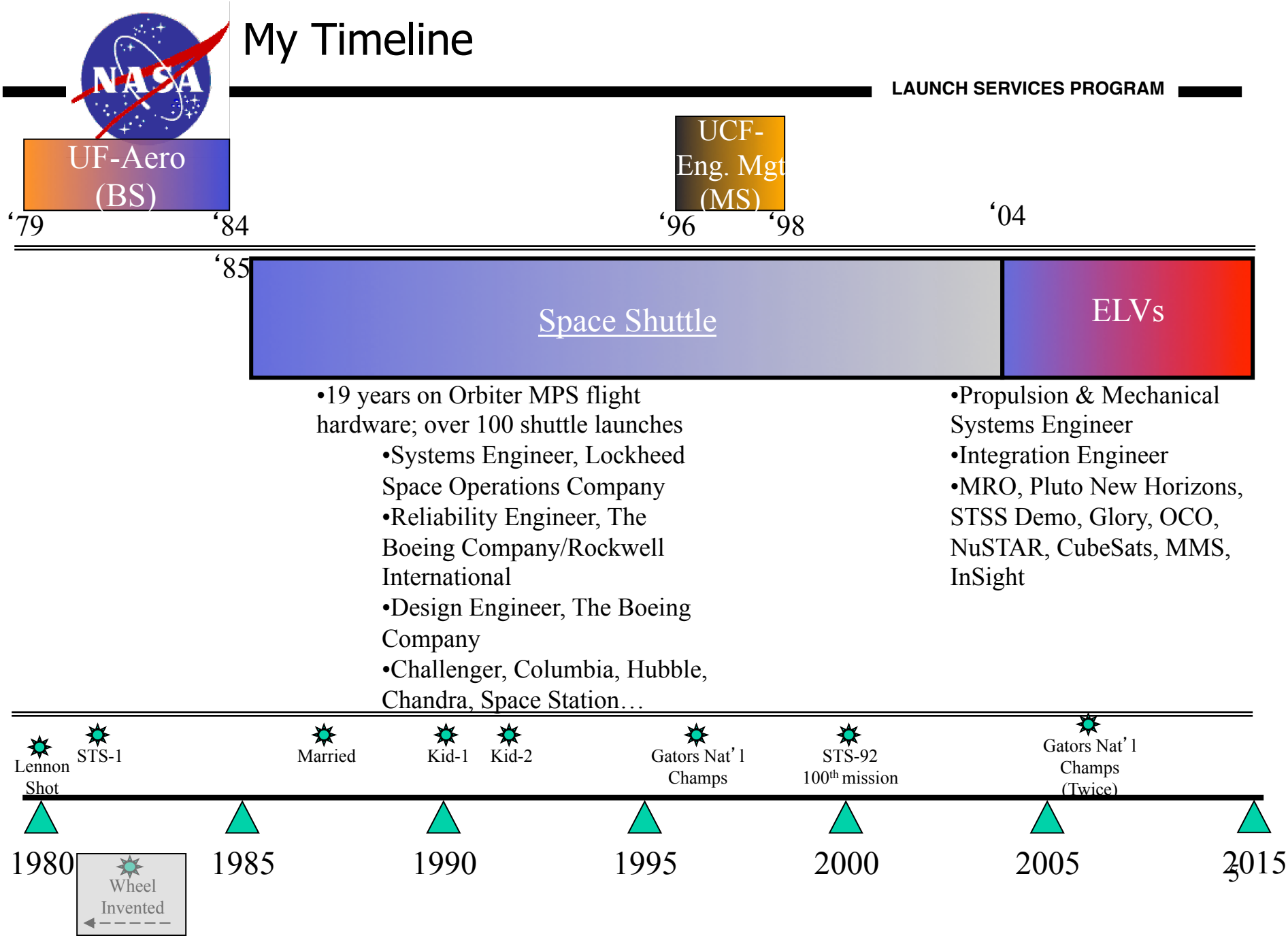
# Who Am I?



- Larry Fineberg, NASA Systems & Integration Engineer, Launch Services Program
  - Approval/Insight for role NASA Missions on Expendable Launch Vehicles
  - Technical role for Mission Life Cycle (~4 years prior to launch until spacecraft separation from Launch Vehicle)
- What is my background?
  - Native Floridian, 1st in family to work in space program
- Education
  - Bachelor's in Aerospace Engineering - 1984 (UF)
  - Master's in Engineering Management –1998 (UCF)
- Work Experience
  - 19 years on Orbiter MPS flight hardware; over 100 shuttle launches
  - 11 years on Expendable Launch Vehicles (ELV)- Pegasus, Taurus, Delta II, Atlas V

# My Timeline




UF-Aero (BS)
UCF-Eng. Mgt (MS)
'79
'84
'96
'98
'04
'85
Space Shuttle
ELVs
•19 years on Orbiter MPS flight hardware; over 100 shuttle launches
•Systems Engineer, Lockheed Space Operations Company
•Reliability Engineer, The Boeing Company/Rockwell International
•Design Engineer, The Boeing Company
•Challenger, Columbia, Hubble, Chandra, Space Station…
•Propulsion & Mechanical Systems Engineer
•Integration Engineer
•MRO, Pluto New Horizons, STSS Demo, Glory, OCO, NuSTAR, CubeSats, MMS, InSight
Lennon Shot
STS-1
Married
Kid-1
Kid-2
Gators Nat'l Champs
STS-92 100th mission
Gators Nat'l Champs (Twice)
1980
1985
1990
1995
2000
2005
2015
Wheel Invented

# Shuttle Orbiter MPS



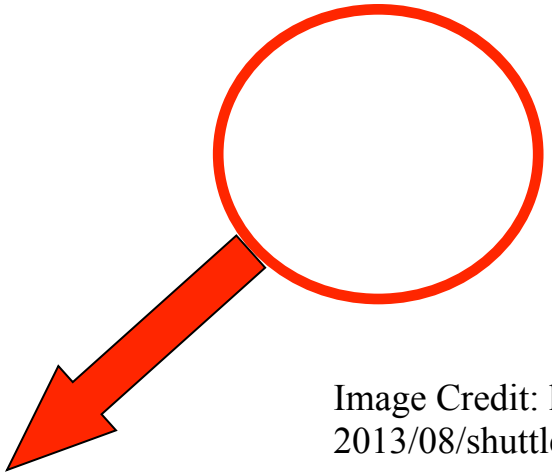


Image Credit: http://21space.info/wp-content/uploads/2013/08/shuttle-far21.jpg

Image Credit: http://www.nasaspaceflight.com/2012/01/engineers-removing-orbiter-mps-components-donation-sls/

# Evolved Expendable Launch Vehicles (EELV)



Image Credit: https://tdelv.ksc.nasa.gov/servlet/dm.web.Fetch/LSP_Fact_Sheet_2014.pdf?gid=78402&FixForIE=LSP_Fact_Sheet_2014.pdf

# "Build Me A Spacecraft"

# Build Me A Spacecraft
# Modular Approach



- Focus on the Science, the purpose of the mission!
  - Payload & Instruments are new everytime
- Utilize proven hardware and systems
  - Bus Systems
  - Landing Systems
  - Prop Systems
- Reduces complexity, cost
- Efficient use of workforce

Image Credit: http://www.nasa.gov/mission_pages/ladee/spacecraft/index.html#.VfL2lelBWhN

# Build Me A Spacecraft Best Practices



- Utilize solid Systems Engineering practices
  - NASA Systems Engineering Processes and Requirements
    - http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1B
- Utilize Best Practices: Lessons learned from the people who have built…succeeded…and sometimes failed. Listen to the greybeards
  - Goddard: Rules for the Design, Development, and Operation of Flight Systems (aka GOLD Rules), GSFC-STD-1000 (http://www.goes-r.gov/syseng/docs/GSFC_STD_1000.pdf)
    - General Environmental Verification Standard (GEVS), GSFC-STD-7000A (https://standards.nasa.gov/documents/detail/3315858)
  - JPL: Best Practices document
- Rely on Specifications wherever possible
  - ISO Standards for cleanliness
  - Range Requirements (EWR 127-1)
  - Standards for processes and controls
  - Electrical components, connectors. wire harnessing
  - Mechanical Assembly
  - The list is long if you take the time to look

# Build Me A Spacecraft Guidelines



- What is the objective of your mission? What are your science goals?
  - Must be Clear. Must be Concise. Easy for the layman to understand. Boil these down to the simplest level, lowest common denominator
  - Mission Overview
    - Figures or views of the spacecraft in its mission phase
  - Flight System Overview
    - Exploded views of the spacecraft major elements
  - Science Objectives
  - Level 0, Level 1, and deeper requirements
    - How long is your commissioning period?
    - How long is your science period?
    - Have you considered de-commissioning or "passivtion"…what happens when your mission is over?

# Build Me A Spacecraft
# Test, Test, and then Test some more



LADEE Thermal Vacuum Preparation:

Technicians at NASA's Ames Research Center, Moffett Field, Calif., install a heater cage around NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) observatory sitting in the base of the thermal-vacuum chamber, in order to simulate the hot and cold extremes the observatory will experience during the mission.
Image credit: NASA Ames

http://www.nasa.gov/mission_pages/LADEE/multimedia/ladee-tvac-prep.html#.VfL4q-lBWhM

# Build Me A Spacecraft
# Test, Test, and then Test some more



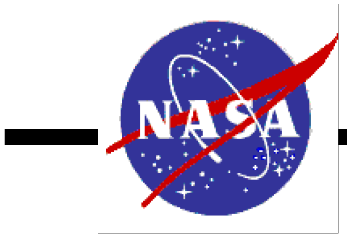
- Model correlation is CRITICAL
- Standard suite of spacecraft factory tests used to verify models
  - As-built meets CAD
  - Vibration, shock, acoustics FEM adequately predict behavior
- You need to show that you have verified and validated your design to environments
  - Qualification
  - Acceptance Test

Image Credit: http://www.onlineamd.com/amd0313-HyperSizer-software-nasa-ames.aspx#.VfL7hOlBWhM

# Project Management



- Who is managing the project?
- Who is building the spacecraft?
- Who is operating the spacecraft during the mission around Mars?






# "Go Get Me A Rocket"

# Mission Flow – Entire Life Cycle At-A-Glance



Image Credit: http://image.slidesharecdn.com/mitskevichamanda-120725121953-phpapp02/95/mitskevich-amanda-8-728.jpg?cb=1343218878

# Evolved Expendable Launch Vehicles (EELV)

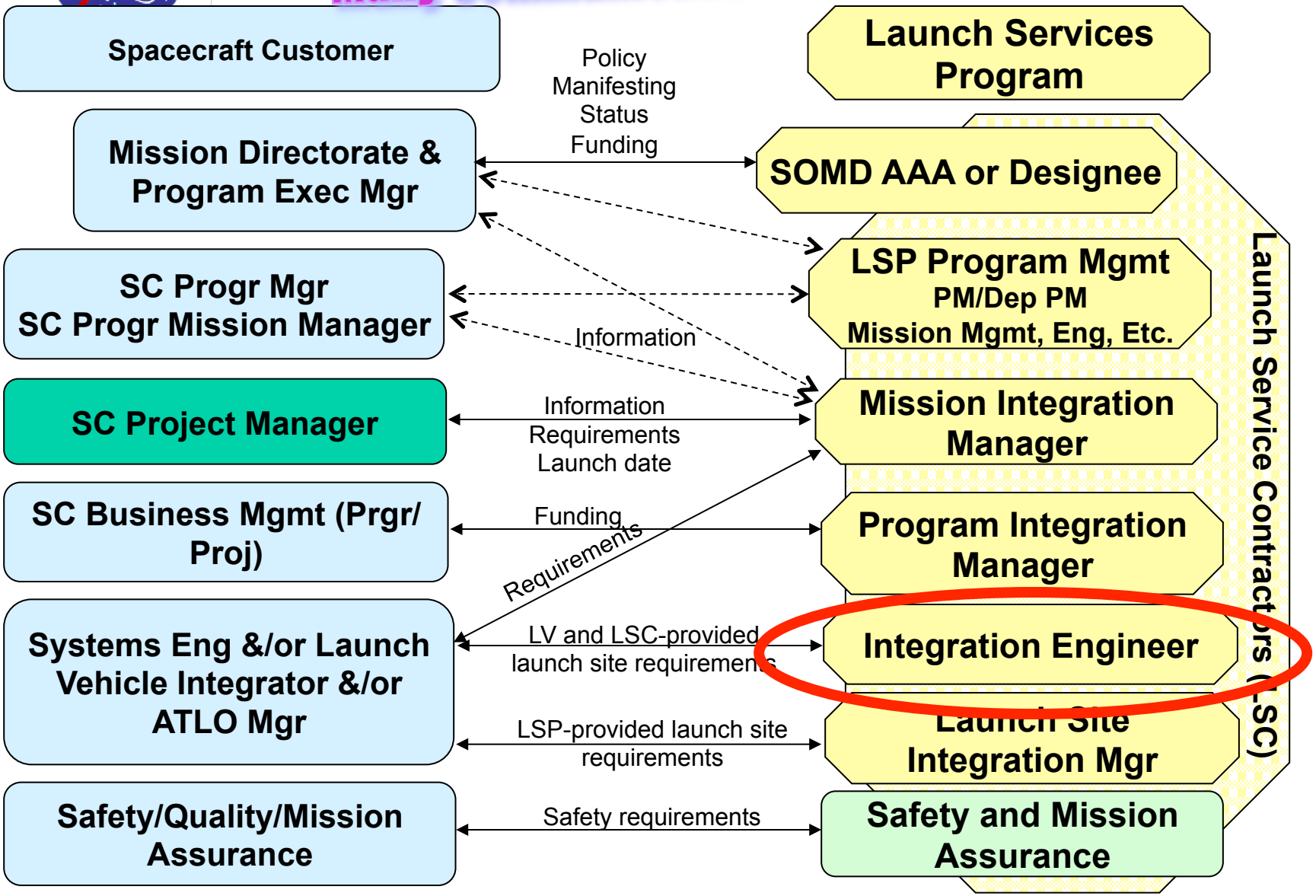


Image Credit: https://tdelv.ksc.nasa.gov/servlet/dm.web.Fetch/LSP_Fact_Sheet_2014.pdf?gid=78402&FixForIE=LSP_Fact_Sheet_2014.pdf

# Launch Services Communication Paths



Many Communication Paths to SC



# Technical Integration



- SC Technical Interface is via Mission Integration Team
  - Mission Manager (Project functions)
  - Integration Engineer (engineering and integration)
  - Launch Site Integration Manager (facilities and operations support)
  - Program Integration Manager (funding)
  - Safety and Mission Assurance

# Evolved Expendable Launch Vehicles (EELV)
# MMS Mission



In a clean room at the Astrotech Space Operations facility in Titusville on Feb. 23, preparations were under way to enclose NASA's Magnetospheric Multiscale observatories (MMS) in an Atlas V rocket's payload fairing for launch.

For more information, visit: http://www.floridatoday.com/story/tech/science/space/2015/03/09/good-forecast-for-thursday-launch-of-nasa-mms-science-mission-from-cape-canaveral/24635837/?from=global&sessionKey=&autologin= Photo credit: NASA/Kim Shiflett

# Evolved Expendable Launch Vehicles (EELV)
# MAVEN Mission



Inside the Payload Hazardous Servicing Facility (PHSF) at NASA's Kennedy Space Center in Florida, engineers and technicians prepare MAVEN for encapsulation inside its payload fairing.



For more information, visit: http://www.nasa.gov/mission_pages/maven/main/index.html.
Photo credit: NASA/Kim Shiflett

# Evolved Expendable Launch Vehicles (EELV)
# MAVEN Mission



Inside the Payload Hazardous Servicing Facility (PHSF) at NASA's Kennedy Space Center in Florida, engineers and technicians prepare MAVEN for encapsulation inside its payload fairing.

# Evolved Expendable Launch Vehicles (EELV)
# MAVEN Mission



Engineers and technicians move MAVEN spacecraft, inside payload fairing, onto a trailer inside the PHSF for transport to Space Launch Complex 41.

For more information, visit: http://www.nasa.gov/mission_pages/maven/main/index.html. Photo credit: NASA/Kim Shiflett

# Evolved Expendable Launch Vehicles (EELV)
# MAVEN Mission



Preps to roll the United Launch Alliance Atlas V rocket carrying NASA's MAVEN spacecraft from the Vertical Integration Facility to Space Launch Complex 41.

For more information, visit: http://www.nasa.gov/mission_pages/maven/main/index.html. Photo credit: NASA/Kim Shiflett

# Evolved Expendable Launch Vehicles (EELV)
# MAVEN Mission



Preps to roll the United Launch Alliance Atlas V rocket carrying NASA's MAVEN spacecraft from the Vertical Integration Facility to Space Launch Complex 41.

For more information, visit: http://www.nasa.gov/mission_pages/maven/main/index.html. Photo credit: NASA/Kim Shiflett

# Interface Requirements: Overall

- Identify the interface requirements for your spacecraft
  - Ask the question: am I designing my spacecraft to the rocket or will the rocket need to accommodate (design) to my spacecraft?
  - Requirements are NOT design solutions
    - Requirements, and their verification, must be carefully crafted
    - Bad requirements beget bad designs
  - Designs satisfy requirements
    - Trade studies
      - Technical complexity (design/operations)/Cost/Schedule
    - The end solution will always be a compromise
      - Balance between cost and complexity
      - Cost: who pays for what changes and out of what budget?
    - Are your design solutions needlessly complex?

# Interface Requirements: Overall



- Know what rocket you will likely be dealing with
  - Every Launch Service Provider (aka rocket manufacturer) produces a *Payload Planner's Guide*
    - Commonly referred to as a PPG
    - Documents everything you need to know at the early stages about the rockets affect on your spacecraft and ability to accommodate your design
      - Standard Services
    - Available on-line, easy Google search, downloadable pdf's

# Using Planner's Guides



- Word of Caution: the PPG should only be used for guidance on design
- The PPG is not always accurate or up to date
  - The PPG is not a guarantee of what the launch service will provide
  - Living document, updated infrequently
  - Examples of errors/out of date info/omissions
    - Acoustic
    - SC static envelope
    - Shock levels (clampband tension)
    - Sine vibe levels
    - EMI/EMC levels
    - Performance (mass delivery to mission specific orbital parameters)

Only a mission specific contract with the provider "locks in" services, performance, interfaces, mission unique services that are not "standard"

# Using Planner's Guides



- Atlas V: http://www.ulalaunch.com/uploads/docs/AtlasVUsersGuide2010.pdf

# Using Planner's Guides



- Atlas V: http://www.ulalaunch.com/uploads/docs/AtlasVUsersGuide2010.pdf

# Using Planner's Guides



- Atlas V: http://www.ulalaunch.com/uploads/docs/AtlasVUsersGuide2010.pdf

# Interface Requirements: Mechanical



**LADEE encapsulated into the Minotaur V fairing** - In this photo, engineers as NASA's Wallops Flight Facility in Virginia encapsule the LADEE spacecraft into the fairing of the Minotaur V launch vehicle nose-cone. LADEE is the first spacecraft designed, developed, built, integrated and tested at NASA's Ames Research Center in Moffett Field, Calif.

Image credit: NASA Wallops / Terry Zaperach. http://esc.gsfc.nasa.gov/assets/images/LLCD/IMG_1933.jpg

# Interface Requirements: Mechanical



- Structural Interfaces
  - Where is the interface with the launch vehicle?
  - Will you fit in the fairing under BOTH static and dynamic conditions
  - Identify dimensions, axes and origins
  - Technical details of the interface design
    - How do the rocket and spacecraft attach? Are you willing to let the rocket manufacturer determine that for you?
- What kind of structural loads can my spacecraft interface withstand?
- Mass Properties
  - Need to consider each of the spacecraft configurations
  - Stowed for launch
  - Mars transit
  - Mission science phase
    - Deployable solar arrays
    - Antennas
    - Mission science instruments
- Access requirements before launch?

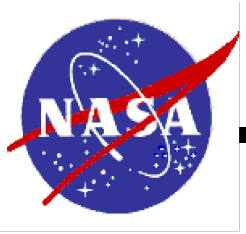
# Interface Requirements: Mechanical



Mass Properties need to stay within the launch vehicle's capabilities

Analogous to balancing a long stick from the bottom…while flying many times the speed of sound

Image credit: http://www.wikihow.com/Balance-a-Lacrosse-Stick



# Spacecraft Envelope



- Do not design to max volume
- SC stay out zones change over time
  - Ensure you understand static and dynamic envelopes
  - Stay clear of the stay out zone below the sep plane
    - Clamp band installation is difficult, keep sensitive instruments away from the clampband installation zone – potential human damage
  - Fairing envelopes – these can change over time
    - Coupled loads analysis
    - Clearance analysis

# Interface Requirements: Electrical



- Airborne Interfaces
  - How many electrical interfaces will you have with the rocket
  - Do you have specific electrical connectors that must be used or will you let the rocket manufacturer determine that for you?
  - Connector pin assignments for power, separation indication, total number of pins per connector
  - How does your spacecraft know when it has separated from the rocket?
    - KISS principle
- Ground Support Equipment (GSE) Interfaces at the launch site
  - What testing do you want to do after your spacecraft is installed on the rocket?
- Telemetry/Command/Data Interfaces at the launch site
  - Consider data formats that the rocket must accommodate at the airborne and ground interfaces
- Ground Interfaces at the launch site
  - What support do you need for your electrical GSE?
    - Power, room heat loads, size restrictions, telephones, comm

# Interface Requirements: Environmental Ground and Rocket Powered Flight



- Thermal Interfaces
  - Spacecraft temperature limits
    - It can get really hot on the launch pad in the summer
    - Cold snaps can drop the temperature to near zero in Florida
    - When powered on for pre-launch checkout, does your spacecraft generate so much heat that it needs to be cooled so damage doesn't occur?
- Dynamic Environments
  - Acoustic, vibration, and shock generated by the rocket must be considered in addition to the dynamic environments encountered during the mission phase
  - These levels will drive your spacecraft testing
- Radiated Emissions Compatibility/Susceptibility
  - Radiation from the rocket compared to spacecraft susceptibility
- Lightning Protection
  - Central Florida is the lightning capital of the US

# EMI/EMC/RF/Electrical



- E-field levels from LV antennas have been found to be greater than the advertised
- Provide adequate EMI protection
- Ensure you understand if margins are included in PPG levels
- Goddard Environmental Verification Specification (GEVS) does not encompass launch site environment – use NASA-STD-7002A, refers to MIL-STD-461
  - hand held devices
  - uncontrollable sources

# Contamination: Launch pads not designed clean



- Contamination
  - How clean does the rocket fairing need to be?
  - How clean does the air supplied to the rocket need to be?
  - Is there a gaseous purge required to inert the environment around a sensitive instrument?
    - Optics considerations
    - Instrument sensitivities to gases, humidity, or condensation
- Cleanliness is difficult to achieve and maintain
  - Provide protection (through launch) for your instruments – e.g. deployable doors/ covers, etc.
  - Plan cleaning into your schedule and for contingencies
  - Sensitive instruments away from the rocket separation system
  - Avoid sensitive instruments pointing forward (particulate released at fairing jettison)
  - Out-gassing materials are present in the fairing and on adapter
  - Contamination requirements are sometimes violated

# Interface Requirements: Environmental Ground and Rocket Powered Flight

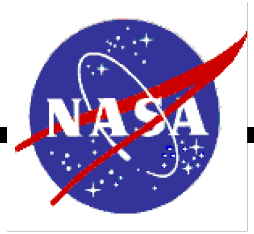


- Planetary Protection
  - NASA HQ directive: Planetary Protection Provisions for Robotic Extraterrestrial Missions
    - http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_8020_012D_&page_name=main
    - Two types of classifications: lander and orbiter
    - Everyone and everything that enters into the airspace around your spacecraft must meet bioburden requirements
    - COMPLIANCE IS MANDATORY

# Air Conditioning



- At the launch complex
  - SC propellant vs. Batteries vs. LV propellant
  - August is hottest month - contingencies or alternate operations if lowest AC setting does not provide adequate cooling
    - But if you are launching in December, you may slip to August! So, design to worst case hot/cold
  - If low end of cold capability required, need requirement early on to be within analytical limits
  - Conflicting requirements between SC and LV
  - Outages happen – contingency planning



# Access at the Launch Complex



- Minimize access needs
  - Its dirty out there - See contamination section
    - Platforms, workstands, clean tents are expensive
    - Account for access to safe and Arm Device (S&A)
      - Fill and drain valve access through the fairing doors
  - Increased access, increases chances for damage
- Don't expect high data rates connecting to your spacecraft
  - Not broadband Ethernet, only what is required during the launch process should be used
  - Lab environment and launch complex / pad environment are very different
    - Distance
    - Wiring

# Interface Requirements: Orbital Parameters/ Insertion



- Launch Period/Window
- Launch Vehicle Performance
- Targeting Errors
- Injection Accuracy
- Thermal Roll
- Separation Requirements
- Post Separation Requirements
- Planetary Protection Biasing: ***missing Mars on purpose***!
- Telemetry & Tracking
- Acquisition Assistance

# Interface Requirements: Launch to SC separation



- Atlas V: http://www.ulalaunch.com/uploads/docs/AtlasVUsersGuide2010.pdf

# Interface Requirements: Trans-Lunar Insertion



http://www.quora.com/Why-is-it-important-that-on-the-launching-day-of-the-Mars-rover-the-two-planets-should-be-close-to-each-other

# Interface Requirements: Mars Orbit Insertion



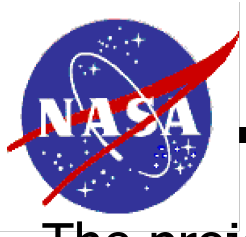
http://
www.americaspace.com/
?p=67789

# Interface Requirements: Environmental Ground and Rocket Powered Flight



- Planetary Protection from a flight design perspective
  - NASA HQ directive: Planetary Protection Provisions for Robotic Extraterrestrial Missions
    - http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_8020_012D_&page_name=main
    - Two types of classifications: lander and orbiter
    - COMPLIANCE IS MANDATORY
  - Planetary Protection requires you design the spacecraft flight path to miss Mars!
    - What if the spacecraft fails to separate from the launch vehicle?
    - Trans-Mars injection parameters actually require spacecraft-launch vehicle separation to occur such the spacecraft misses Mars
    - Removes risk that LV spent stage follows spacecraft to Mars
    - Requirement states you must propagate spent stage orbit for the next 50 years!

Spacecraft design must include fuel reserves to bring flight path back into a Mars intersecting trajectory



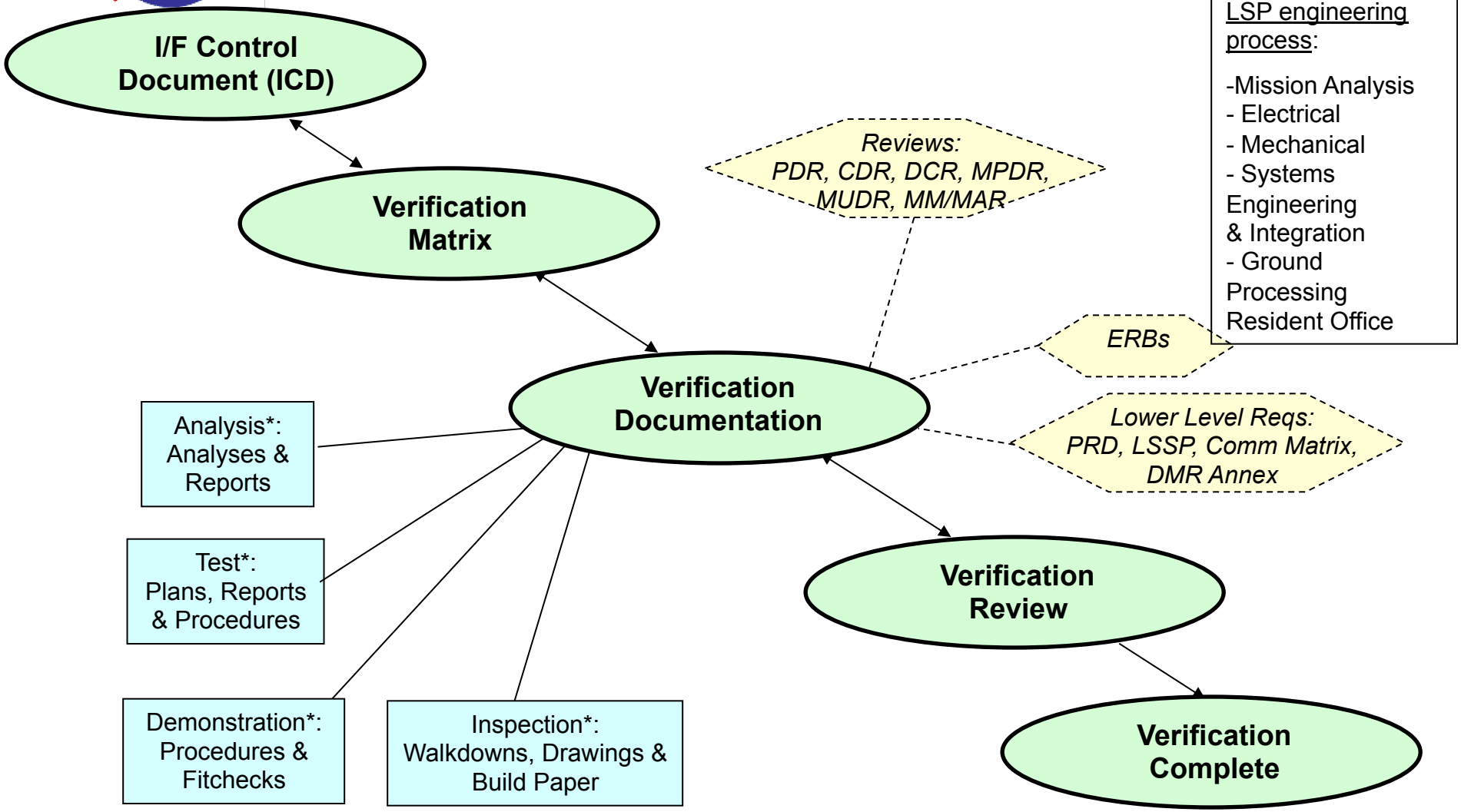
# Interface Requirements: Verification



- The project management must show each other that they have verified the the interface requirements.
- Its not enough to "say" you verified each requirement, you have to prove it with analysis or testing
- Spacecraft testing before shipment to the launch site
  - Thermal vacuum
  - Vibration
  - Shock
  - Electromagnetic radiation
  - Electrical
  - Mechanical

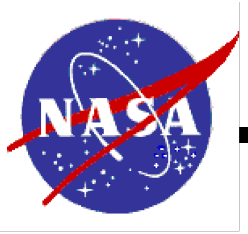
# LSP ICD Verification Process








* LSP performs ICD verification of SC/LV interfaces using both SC and LSC data and documentation



# Requirements Documents



- Interface Requirements Document (IRD)  (aka SC Questionnaire)
  - IRD is the document to provide your requirements to the launch vehicle (LV)
  - SC-owned document
  - Usually used as the requirements in a LSC competition (launch service task order (LSTO))
  - Write your requirements, *not LV design solutions*
- Interface Control Document (ICD)
  - The ICD will be agreed to and signed by LSP, LSC, and SC
    - LSP must follow LSP-P-330.07, Interface Control Document (ICD) Development, Change and Approval Process for LSP Missions
    - Requires Engineering Review Board (ERB) prior to LSP signature
  - If LSC provides it, it must be in the ICD
  - KSC will process a Waiver request following LSP Interface Control Document (ICD) Waiver Process (LSP-P-333.11)
  - Waivers are usually only granted in extraordinary circumstances, LSP usually requires SC or LV perform the necessary action meet the original ICD requirement

IRD and ICD are critical documents for SC and LV design

# Interface Verification Flowdown (con't)



- This independent verification task is a LSP responsibility (LSP ICD Verification Process, LSP-P-333.08)
  - Typically utilizes the same documentation for verification closure as the LSP process, but may require additional / different supporting documentation
  - Documentation supporting compliance with the requirements must be official documentation (i.e. Plan, Procedure, Analysis Memo, Test Data Summary). Nominally, a memo stating "we comply with…" is inadequate. LSP requires data, analysis, test, inspection to show compliance
- Every requirement in the ICD is identified for verification
  - Both launch service contractor and SC are required to provide supporting documentation to LSP showing compliance with the requirements
- Incremental verifications are performed for many items
  - e.g. Drawing, released procedure, fitcheck, flight mate, as-run procedures
  - e.g. Test Plan, Test Results, Test Summary

# Integrated Operations



- LSP has approval for integrated operations - final step in ICD verification process
- At the SC factory
  - Fitcheck
  - Test adapters for testing
  - Harnesses
  - Pathfinders
- At the launch site
  - Touch and go
  - SC mate to adapter
  - Fairing installation (occurs at processing facility or Pad depending upon vehicle)
  - SC transport to pad (ground or flight)
  - Integrated electrical tests
  - SC closeouts

# Lessons Learned



- The most valuable things I've learned from my degree
  - How to solve a problem and how to make assumptions, compromises
  - The ability to understand the basis of conclusions from other engineering disciplines

- The most valuable things I've learned since I started working
  - BE CREATIVE ! That's where all of the breakthroughs come from
  - Work to Live…not Live to Work. Do not let work become your whole life
  - Decisions or requirements that appear stupid generally are NOT. Decisions factors are not always apparent
  - Invest, to the max, in your company's 401k plans

- New Engineers ("Fresh Outs") are an extremely valuable resource
  - Out-of-the-box thinkers; bring fresh approaches & new technologies
  - Makes us ask "why"
  - The future of the industry
  - They are much cheaper and more flexible than the "graybeards" or "yodas"

- Favorite Quotes, or words to live by
  - Whether you think can or can't…you're right (Henry Ford)
  - "Don't judge a book by it's cover" – not true. You are judged by your attitude, work ethic, and writing / speaking skills. It may not be fair, but that is the way it is.
  - Better to keep your mouth shut & look dumb, then open it & remove all doubt!

# Lessons Learned

- Don't Do This
  - If you don't know the answer to something… DO NOT make up or guess an answer. Correct reply: "I don't know but I'll find out".

- Do This
  - Be proactive. Be positive. Be a "go-getter". Who would you pick for the cool jobs: the engineer with the go-getter attitude or the one who sits back and waits to be told what to do and how to do it?
  - Admit when you are wrong. You waste valuable mental resources defending yourself when you could be using yourself more productively.
  - Always be thinking 10 steps ahead. It makes you more prepared and efficient.

- Remember this
  - In real life, all of your problems are word problems. Better start enjoying them now.

# Questions?